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ENERGY COMMISSION**



California Energy Commission
Clean Transportation Program

FINAL PROJECT REPORT

San Ramon Hydrogen Fueling Station

Prepared for: California Energy Commission

Prepared by: Linde LLC

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- California Energy Commission
- Quantum Technologies
- Smart Chemistry
- First Element
- South Coast Air Quality Management District

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to \$20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about \$100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-13-607 to develop infrastructure necessary to dispense hydrogen transportation fuel and to support hydrogen refueling operations prior to large-scale roll-out of fuel cell vehicles. In response to PON-13-607, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards May 1, 2014 and the agreement was executed as ARV-14-018 on October 16, 2014.

ABSTRACT

Linde LLC has successfully designed, constructed, commissioned and opened the San Ramon Hydrogen Refueling Station which is approved to sell hydrogen by the kilogram by the California Department of Food and Agriculture/Division of Measurement Standards. This station is open to the public, accepts most major credit cards, and performs refueling of fuel cell electric vehicles in 3 minutes at both 350 bar and 700 bar hydrogen tank pressures. This final report describes the performance, economic benefits, and local impact of the project and summarizes the operational data collected under Task 5 Data Collection and Analysis.

Keywords: Linde, fuel cell electric vehicle, hydrogen, station

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TABLE OF CONTENTS

	Page
Acknowledgements	i
Preface	ii
Abstract	iii
Table of Contents	v
List of Figures	v
List of Tables.....	vi
Executive Summary	1
CHAPTER 1: Station Design and Construction.....	3
1.1 Timeline	3
1.2 Location	5
1.3 Environmental impacts.....	5
1.4 Station’s place in the fueling network.....	7
1.5 Photographs of the finished station.....	8
1.6 Site Drawings.....	11
1.7 Project costs and funding received from CEC	11
1.8 List of Major Subcontractors.....	11
CHAPTER 2: Data Collection and Analysis	13
2.1 Hydrogen Supply and Performance Statistics	13
2.2 Current and Planned use of Renewable Energy	14
2.3 Energy Efficiency.....	14
2.4 Economic Development.....	14
2.5 Life Cycle Green House Gas Emissions	14
2.6 Transition to Alternative Fuels	15
2.7 Sustainability Goals 20 CCR Section 3101.5	15
2.8 Actual vs. Proposed Performance.....	15
CHAPTER 3: Conclusion.....	17
Glossary.....	18

LIST OF FIGURES

	Page
Figure 1: Block Diagram of the San Ramon Hydrogen Refueling Station	3
Figure 2: Final Site Location at 4475 Norris Canyon Road, San Ramon, CA	5

Figure 3: From the California Fuel Cell Partnership: Greenhouse Gas Emissions based on the Argonne National Lab GREET V1_2013 model	6
Figure 4: GREET Model Results for Criteria Pollution based on the Argonne National Lab, GREET V1_2013 model	7
Figure 5: Linde LLC San Ramon Hydrogen Refueling Station is in the Alameda & Contra Costa County Cluster.....	8
Figure 6: Station Photos.....	9
Figure 7: Station Photos.....	10
Figure 8: San Ramon Hydrogen Refueling Station Plot Plan	11
Figure 9: San Ramon Hydrogen Refueling Station – Subcontractor List.....	12

LIST OF TABLES

	Page
Table 1: Project Timeline.....	4
Table 2: San Ramon Hydrogen Refueling Station Usage.....	13
Table 3: San Ramon Hydrogen Refueling Station Statistics From Commissioning 7/18/2017 to 12/1/2017.....	13
Table 4: PON-13-607 Minimum Technical Performance	15
Table 5: Proposed estimated demand (kg/day)	16

EXECUTIVE SUMMARY

Hydrogen fuel cell electric vehicles and hydrogen refueling stations are expected to play key roles in California as the state transitions to lower-carbon and zero-emission vehicle technologies for light-duty passenger vehicles, transit buses, and truck transport fleets. Numerous government regulations and policy actions identify fuel cell electric vehicles as a vehicle technology that will be available to meet the California Air Resources Board Zero Emission Vehicle Regulation and the governor's Zero Emission Vehicle Mandate. More specific actions to bring fuel cell electric vehicles to California markets are specified in the governor's Zero Emission Vehicle Action Plan.

Hydrogen fuel cell electric drive technology offers tremendous potential for the light-duty passenger vehicle market and medium- and heavy-duty truck and bus markets. Fuel cell electric vehicle passenger vehicles can drive more than 300 miles on a tank of hydrogen and can be refueled in three to four minutes the way gasoline passenger vehicles are fueled. They have zero tailpipe emissions, while the carbon footprint of these vehicles is nearly the same as plug-in electric vehicles. The technology can be readily scaled up for sport utility vehicles, family passenger vans, pick-up trucks, urban package and beverage delivery trucks, and even heavy-duty trucks and buses. Most auto industry analysts and agencies view fuel cell electric drive technology as a complement to battery electric drive technologies, rather than as a competing technology. Both battery and fuel cell electric vehicle technologies will be needed in California to achieve the zero emission vehicle deployment goals.

In contrast to battery electric and plug-in hybrid electric vehicles that can be charged in home settings, fuel cell electric vehicles require a new network of refueling stations that dispense pressurized hydrogen for consumer use. This has meant that the auto industry and station development industry have had to co-develop two new technologies in parallel: hydrogen refueling infrastructure and hydrogen fuel cell electric vehicles. Fuel cell electric vehicles cannot be widely marketed and sold to consumers without a minimum network of refueling stations available.

Linde LLC has proven at the San Ramon Hydrogen Refueling Station that the ATZ IC90 compressor system is capable of performing fast cold fills for both 350 bar and 700 bar light duty hydrogen vehicles with up to 5 kilograms of onboard hydrogen storage. This station stores liquid hydrogen on site and utilizes the ATZ IC90 high throughput hydrogen compressor, which has the capability to scale with the growing light duty fuel cell electric vehicle market. The dual hose dispenser allows for filling of both 350 bar and 700 bar class hydrogen vehicles with tanks less than 10 kilograms.

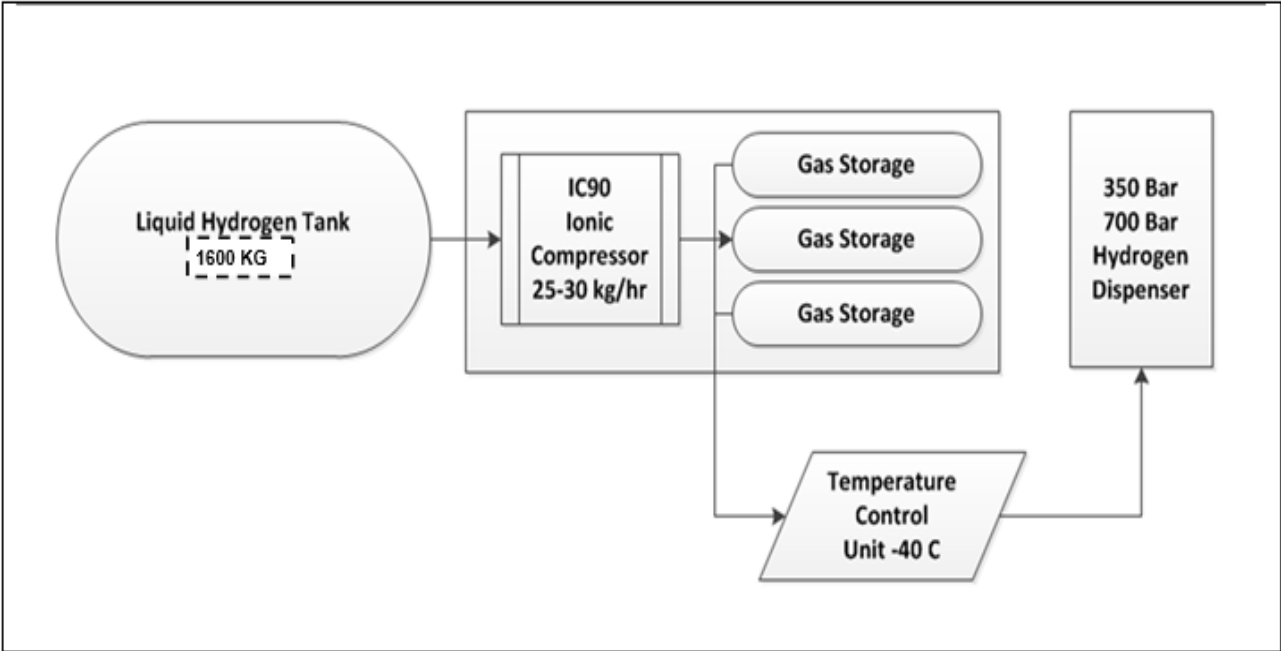
Linde LLC has also proven the station's capability of accurately dispensing hydrogen by being approved to sell hydrogen by the kilogram by the California Department of Food and Agriculture/Division of Measurement Standards.

CHAPTER 1:

Station Design and Construction

Linde LLC utilized the ATZ IC90 ionic compressor for hydrogen compression for increased capacity and efficiency. This is the Linde LLC standard technology for future stations. The Linde LLC San Ramon Hydrogen Refueling Station stores 1600 kilograms (kg) of liquid hydrogen on site and dispenses the hydrogen via high pressure storage tubes which are supplied from the ATZ IC90 compressor as shown in Figure 1.

Figure 1: Block Diagram of the San Ramon Hydrogen Refueling Station



The ATZ IC90 station compressor can sustain a flow rate of 25 to 30 kg per hour depending on inlet temperature and pressure which varies due to ambient conditions, utilization, and liquid tank controls. Additionally, the station is designed with room for a second ATZ IC90 compressor to be installed in the same compressor container, which could double the station performance.

1.1 Timeline

The timetable from the proposal is shown below in Table 1. The planned date for each major milestone is shown with the actual date and justification for changes to the schedule. Overall, the technical aspects of the project proceeded on time while the project development, site selection, and local jurisdiction approval took longer than anticipated.

Table 1: Project Timeline

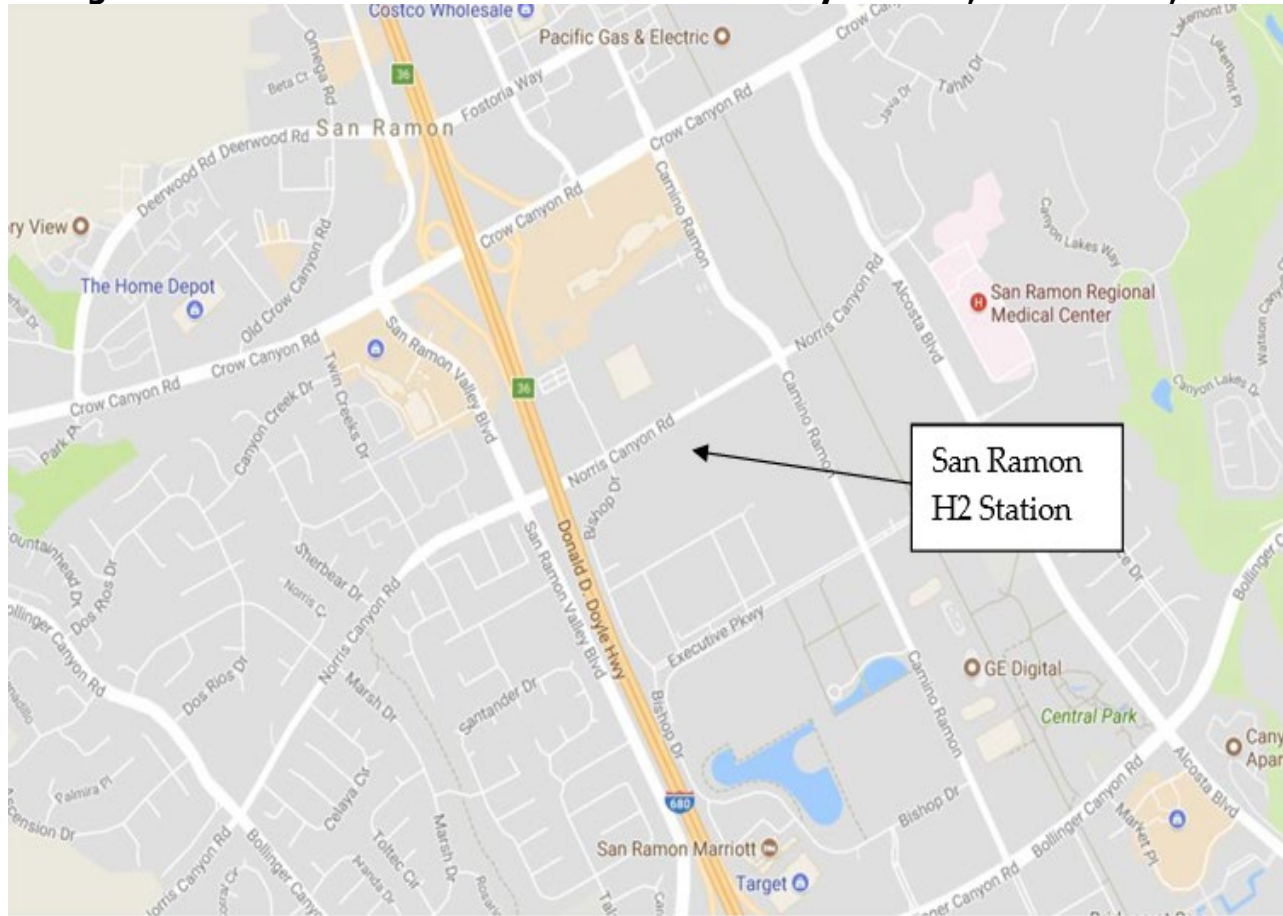
Event	Target Date	Actual Date	Justification
Award approval at California Energy Commission (CEC)	July-14	July-14	
Anticipated Contract Execution	July 14	Sep-14	With lease contract negotiation challenges and change in site size, contract execution and project kick-off could not be initiated
Project Kick Off (Authority to Proceed)	Sept-14	May-15	With lease contract negotiation challenges and change in site size, contract execution and project kick- off could not be initiated
Secure Planning Approval and Building Permits	May-15	April-16	Site Planning and Permitting was delayed due to extended City plan review and permit process.
Equipment Released for shipment to site	May-15	Apr-16	Delays due to site and permitting. Equipment was tested and ready April 2015.
Begin Site Work (concrete, trenching, excavation)	June-15	June-16	
Install	July-15	Sep-16	
Substantial Completion	Sep-15	Dec-16	
Commissioning	Sep-15	May-17	Delayed due to Pacific Gas and Electric duration to provide permanent power to the site.
California Department of Food and Agriculture/Division of Measurement Standards Division of Measurement Standards/Hystep	October-15	July-17	
Open	November-15	July-17	

Source: Linde LLC

1.2 Location

The Linde LLC San Ramon Hydrogen Refueling Station is located at 4475 Norris Canyon Road, San Ramon, California 94583 as shown in Figure 2.

Figure 2: Final Site Location at 4475 Norris Canyon Road, San Ramon, CA

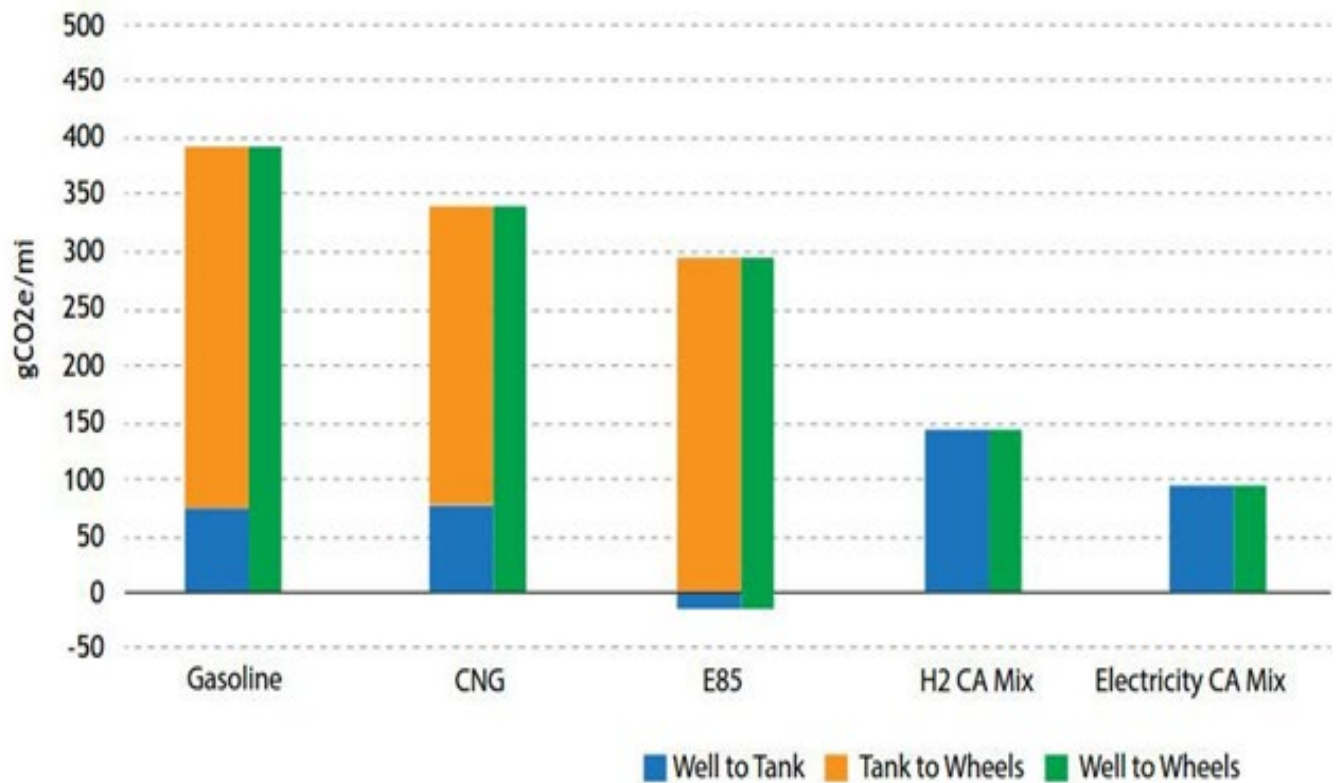


Source: Linde LLC

1.3 Environmental impacts

From station construction through the first four months of operation since the San Ramon Hydrogen Refueling Station was commissioned, there have been zero incidents that have negatively impacted the environment. From station commissioning to the end of November 2017, 6,300 kg of hydrogen was dispensed. Assuming a fuel cell electric vehicle (FCEV) delivers 60 miles/kg of hydrogen, there was a greenhouse gas emission reduction of 90.7 metric tons. This assumes the difference in emission between gasoline and hydrogen is 240 grams of carbon dioxide equivalent per mile, as taken from the California Fuel Cell Partnership report based on the Argonne National Lab GREET V1_2013 model shown in the graph on Figure 3. These results show a positive impact to the environment.

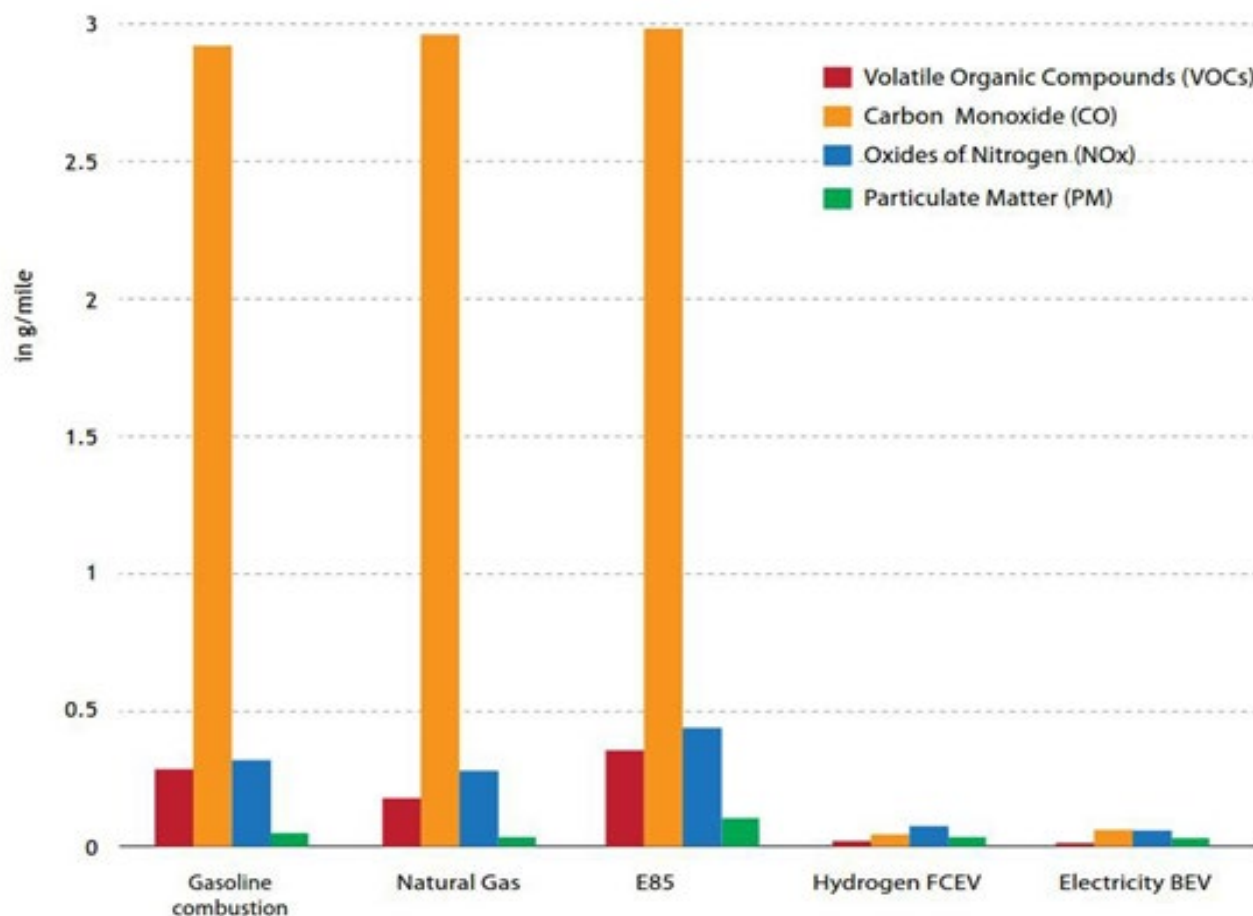
Figure 3: From the California Fuel Cell Partnership: Greenhouse Gas Emissions based on the Argonne National Lab GREET V1_2013 model



Source: California Fuel Cell Partnership

Additionally, as shown in Figure 4, there is a reduction in volatile organic compounds, carbon monoxide, oxides of nitrogen, and particulate matter with the displacement of gasoline.

Figure 4: GREET Model Results for Criteria Pollution based on the Argonne National Lab, GREET V1_2013 model

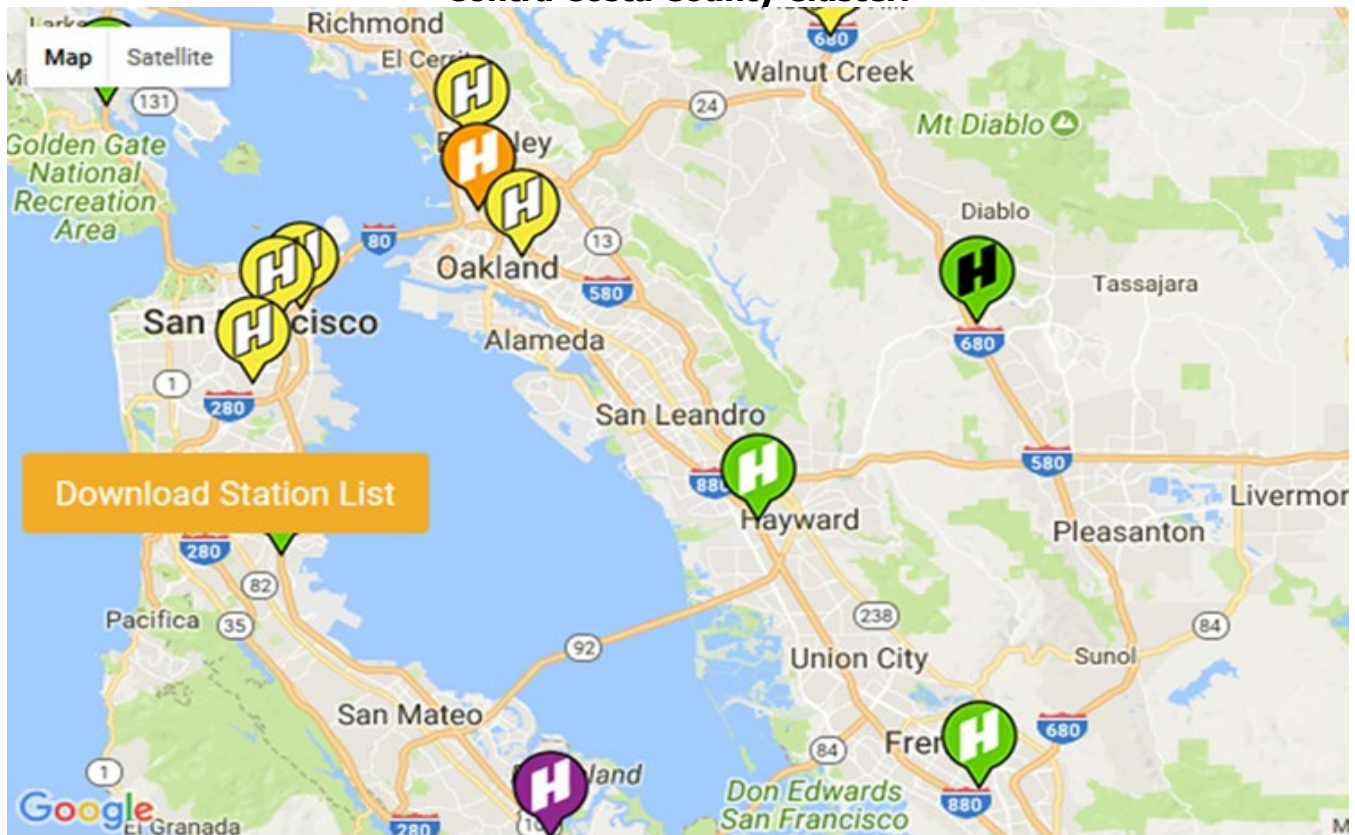


Source: California Fuel Cell Partnership

1.4 Station's place in the fueling network

San Ramon is an emerging hydrogen fuel market. The station is located at the Bishop Ranch Industrial Park and is off I-680 in Contra Costa County. This location is in the cluster of fuel stations in Alameda and Contra Costa Counties and is used by commuters to the area. The location is shown on the [California Fuel Cell Partnership website](http://cafcp.org/stationmap), <http://cafcp.org/stationmap>, and in Figure 5.

Figure 5: Linde LLC San Ramon Hydrogen Refueling Station is in the Alameda & Contra Costa County Cluster.



Source: Linde LLC

1.5 Photographs of the finished station

The following photos show the completed filling station below in Figure 6 and Figure 7. The station is open to the public, however the liquid hydrogen tank and ATZ IC90 compressor are behind the wall and fence inside the equipment pen. The site is easily viewed from the street.

Figure 6: Station Photos



Source: Linde LLC

Figure 7: Station Photos

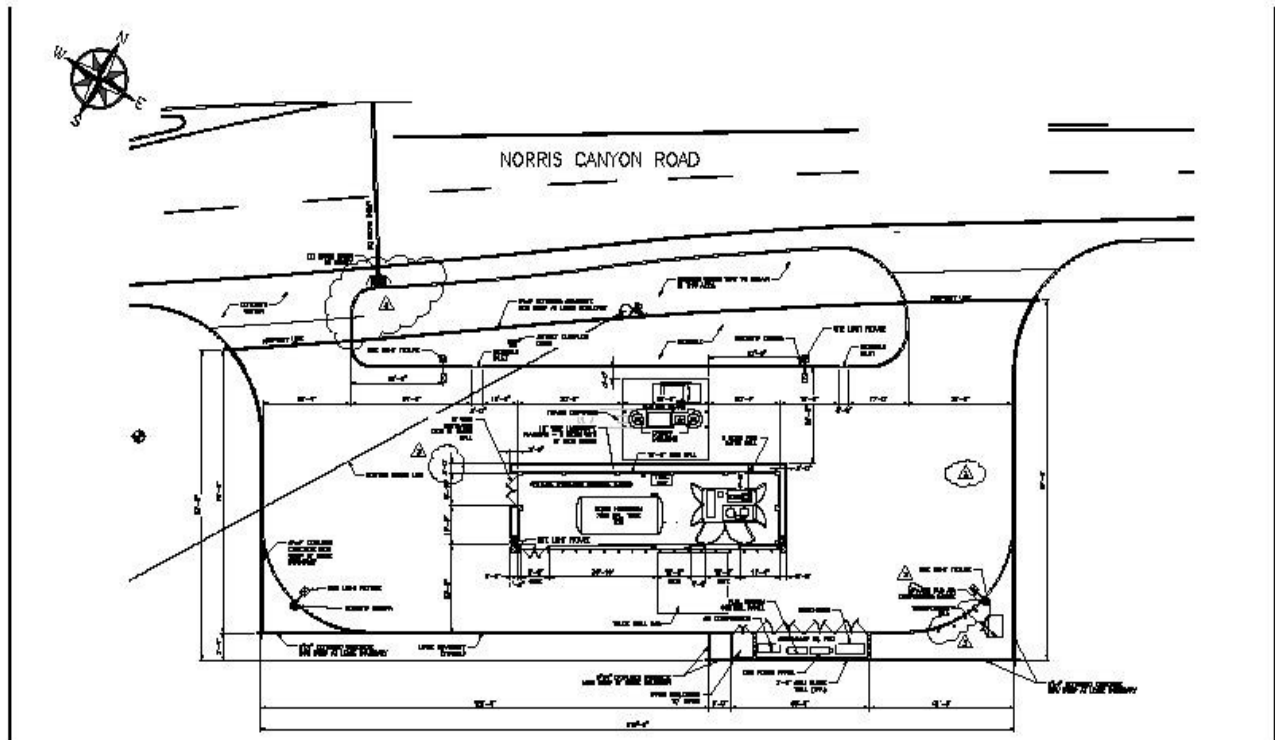


Source: Linde LLC

1.6 Site Drawings

The plot plan for the San Ramon Hydrogen Refueling Station is shown below in Figure 8. The proper setbacks for liquid hydrogen and high pressure gas storage fit well on the site. The equipment layout with the ATZ IC90 and liquid tank is now a standard design basis for future site selection for Linde LLC. Several improvements to the overall equipment layout have been identified and planned for implementation in future sites. The most significant change is that the high pressure storage shown between the ATZ IC90 and liquid tank are planned to be integrated into the ATZ IC90 container which will reduce the overall footprint. Additionally the ATZ IC90 controls system will be installed in a remotely located panel to reduce the air purge requirements and power consumption.

Figure 8: San Ramon Hydrogen Refueling Station Plot Plan



Source: Linde LLC

1.7 Project costs and funding received from CEC

The total cost for the new station is \$3,375,173 which was considerably higher than the approved budget of \$2,783,400.00. This was due to many unforeseen delays with location and permitting issues and construction issues with Pacific Gas and Electric supply of electrical service to the site. Several budget changes were executed to reallocate funds from one category to another. These changes were necessary due to the site change, varying costs due to the long duration of the project, and the change in contractor scopes.

1.8 List of Major Subcontractors

Figure 9 below is a screenshot of a table that lists the major subcontractors for the San Ramon Hydrogen Fueling Station.

Figure 9: San Ramon Hydrogen Refueling Station – Subcontractor List

Vendor Name	Address	Scope of Services	Value
ACME Cryogenics	2801 Mitchell Ave, Allentown PA	Tank Piping & Acc	\$7,534.00
Apex Refrigeration Services	1 <u>Winemaster Way</u> , Lodi, CA 95240	Refrigeration Services	\$11,693.00
Cleary Brothers Landscape	PO Box 3577, Danville, CA 94526	Landscape Services	\$41,882.00
Consolidated Engineering	2001 Crow Canyon Road, San Ramon, CA	Civil Testing Services	\$17,962.00
CTE	730 Peachtree Street, Atlanta, GA	Engineering Services	\$15,918.00
EPC, LLC	3609 Wadsworth Blvd, Lakewood, CO	Engineering Services	\$122,699.00
<u>Fastech, Inc.</u>	7050 Village Drive, Buena Park, CA 90621	General Contractor	\$1,221,625.00
Golden State EPC	2730 Oak Road, Walnut Creek, CA 94597	Engineering Services	\$93,375.00
LHL Construction	3221 <u>Ripsey Road</u> , Loomis, CA 95650	Canopy Services	\$28,299.00
Mallory Safety	5510 E. Marginal Way S., Seattle, WA 98134	Construction Manage	\$171,323.00
Pacific Gas & Electric	PO Box 997340, Sacramento, CA	Electric Services	\$51,081.00
Sac Valley Electric	24 Blue Sky Ct., Sacramento CA	Electric Services	\$102,465.00
Smart Chemistry	3401 La Grande Blvd. Sacramento, CA	Gas Testing Services	\$4,700.00
<u>The Spear Group</u>	5550 Triangle Parkway, Norcross, GA 30092	Construction Manage	\$19,603.00

Source: Linde LLC

CHAPTER 2:

Data Collection and Analysis

The goal of this task is to collect at least 12 months of data on the performance, economic benefits and local impact of the project throughout the term of the project and to analyze the sustainability of the San Ramon Hydrogen Refueling Station. The usage of the station during the writing of this report and since initial commissioning is as shown below in Table 2.

Table 2: San Ramon Hydrogen Refueling Station Usage

Month	Kg
Jul-17	210.8
Aug-17	1275.6
Sep-17	1863.5
Oct-17	1845.9
Nov-17	1750.2

Source: Linde LLC

2.1 Hydrogen Supply and Performance Statistics

The hydrogen supply for the San Ramon Hydrogen Refueling Station was obtained from a production source located in the Los Angeles area. This same supply was used for the entire funded period of the project and is planned to remain the supply source in the future with potentially additional supply from green sources as discussed in section 2.5 below. The performance statistics of the San Ramon Hydrogen Refueling Station from July 18, 2017 to December 1, 2017 are shown below in Table 3.

Table 3: San Ramon Hydrogen Refueling Station Statistics From Commissioning 7/18/2017 to 12/1/2017

Description	Value
Total kg of Hydrogen Dispensed, kg	6945
Average kg/day	51
Approximate % of H70	95
Approximate % of H35	5
Number of Days Vehicles Filled	136
Number of Transactions (~Vehicles Filled)	1999
Average fill (kg)	3.47
Average Transactions per day	14.6
Total Gallons of Gasoline equivalent displaced (1 gallon = 0.997 kg)	6280

Source: Linde, LLC

2.2 Current and Planned use of Renewable Energy

The hydrogen at the San Ramon Hydrogen Refueling Station is planned to be 33 percent renewable, either by purchasing credits to meet 33 percent renewables or delivering renewable hydrogen from a facility from outside the state to meet the 33 percent requirements.

2.3 Energy Efficiency

The ATZ IC90 has a 73 percent isentropic efficiency. The entire fuel station electrical consumption can vary due to ambient temperature and station utilization. The station requires a base load for the refrigeration system which cycles on and off automatically to maintain the cold fill heat exchangers at -40 Celsius. On a per kg basis, the refrigeration energy is reduced by taking advantage of the cold temperatures in the liquid hydrogen tank. These cold temperatures cool the cold fill heat exchangers and reduce the refrigeration system load. This is more efficient than using only electricity to maintain the cold temperature.

Linde LLC has also improved site power consumption at San Ramon by eliminating the need for purged air cabinets by installing the cabinets outside the classified area.

2.4 Economic Development

During construction, hours worked by contractors were approximately 1,384 hours/month for five months. This translates to 10 full time jobs during the five months of construction. For operation and maintenance, Linde LLC anticipates 10-20 percent of a full time equivalent in the early years growing thereafter based on volume and station utilization. During construction, commissioning, Department of Food and Agriculture/Division of Measurement Standards testing, original equipment manufacturer testing, and public events, significant business has been given to local vendors, labor, hotels and restaurants. Continued economic development would include this station's contribution to a new market supporting local sale of fuel cell electric vehicles.

2.5 Life Cycle Green House Gas Emissions

This project reduces greenhouse gas emissions through the supply of a low carbon fuel, hydrogen, for zero emission vehicles. Hydrogen fuel cell vehicles reduce greenhouse gas emissions up to 40 percent compared to conventional gasoline-powered vehicles on a well-to-wheels basis based on the California Air Resources Board GREET model.

Hydrogen supplied to fuel cell vehicles is among the lowest carbon fuels available for use as transportation fuel. The total carbon reduction potential from the San Ramon Hydrogen Refueling Station is significant due to its 350 kg per day compressor nameplate capacity.

As of July 2017, the San Ramon Hydrogen Refueling Station had passed Department of Food and Agriculture/Division of Measurement Standards certification testing and received more than two original equipment manufacturer letters of support, allowing it to be declared officially open. The station is currently in the full open status and should encourage more use of the station and car sales in the area.

2.6 Transition to Alternative Fuels

The San Ramon Hydrogen Refueling Station displaced approximately 6,000 gallons of gas equivalent during its first four months in operation. It is estimated that hundreds of people who have now seen the Linde LLC dispenser in use will be more comfortable buying an FCEV because they know where to fuel. Linde LLC staff regularly had people stopping by to ask about the station while it was under construction and commissioning. They stated that they were interested in buying an FCEV when they become available because they know they can fill up at the Linde San Ramon Hydrogen Refueling Station. Greater use of FCEVs by local residents, as well as local city and state government offices, will dramatically increase the awareness and transition to hydrogen as an alternative transportation fuel.

2.7 Sustainability Goals 20 CCR Section 3101.5

This station's design and operation comply with the CEC's Program Opportunity Notice requirements and support 20 CCR Section 3101.5. The goal of 20 CCR Section 3101.5 is to ensure that funded projects promote sustainable alternative fuels and vehicles by reducing greenhouse gas emissions associated with California's transportation system, protecting the environment, and enhancing market and public acceptance of sustainably produced alternative and renewable fuels. The station utilization is key to ensuring financial viability of the station and continued development of future stations for all station developers. A rapid increase in utilization of new FCEVs will be an important step in the growth of the market.

2.8 Actual vs. Proposed Performance

The San Ramon Hydrogen Refueling Station meets or exceeds all the minimum technical requirements from the Energy Commission issued solicitation PON-13-607. The minimum performance for the San Ramon Hydrogen Refueling Station is as shown in Table 4, although we have demonstrated greater performance during the initial operation of the station.

Table 4: PON-13-607 Minimum Technical Performance

100 kg/day Minimum capacity over a 12-hour period.
350 bar (35 megapascals) and 700 bar (70 megapascals) dispensing pressures
Compliance with Society of Automotive Engineers-2799/J- 2601/J-2719/2600

Source: Linde LLC

The San Ramon Hydrogen Refueling Station was estimated to see 20 kg/day in year one, ramping up to 99 kg/day in year six. This is a developing market. Linde LLC has seen a recent increasing trend in the station demand and was hopeful that 2018 could provide additional car sales and station demand. Additional stations in the area will help increase vehicle adoption and demand on the Linde LLC station, which will improve the business case for Linde LLC to develop additional stations. The 2010 planned station demand in kg/day is shown in Table 5. Currently the station supplies, on average 50-60 kg/day, well above the predicted 20kg/day in year one.

Table 5: Proposed estimated demand (kg/day)

Years Open	Kg/day
Year 1	20
Year 2	26
Year 3	53
Year 4	68
Year 5	99
Year 6	99

Source: Linde LLC

CHAPTER 3:

Conclusion

Linde LLC is now operating three, high-capacity, liquid hydrogen based fueling stations to supply light duty vehicles in California in addition to the bus and light duty vehicle fueling stations at AC Transit in Emeryville and Oakland, California. Linde LLC appreciates the support of the State of California and the entire hydrogen community to develop the hydrogen fuel market. This is a great step forward for the State of California and Linde LLC to lead the nation with hydrogen zero emissions vehicles infrastructure and technology deployment. Linde LLC is looking forward to continuing to develop the hydrogen fuel technology and market with collaboration with the State of California, stakeholders and industry leaders. The support from this project has contributed to the commercialization of the ATZ IC90 ionic compressor which is becoming the industry standard for station developers and facilitated real world verification of liquid hydrogen supply, storage and 700 bar gaseous dispensing as a valid hydrogen pathway for this market.

GLOSSARY

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

1. Forecasting future statewide energy needs
2. Licensing power plants sufficient to meet those needs
3. Promoting energy conservation and efficiency measures
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
5. Planning for and directing state response to energy emergencies.

FUEL CELL ELECTRIC VEHICLE (FCEV)—A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle

KILOGRAM (kg)—The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1,000 cubic centimeters of water at the temperature of its maximum density.